# Parametric Study of a Two-Stage Betatron Collimation for the PS2

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30th September 2010

# Outline

# Why a Collimation System for PS2?

PS2 is a **high intensity** ($E_{kinet}$=4-50 GeV, $I_{FT}$= 1 $10^{14}$ppp) synchrotron under design to replace the current CERN PS.

Beam losses are a concern, so **low loss design approach is adopted** e.g. transition crossing avoided, space charge effect minimized (raised injection energy)...

Certain percentage of losses are **unavoidable** → collimation system,

- allowing fast interventions and hands-on maintenance
- protecting machine devices
- provide flexibility for future upgrades in the machine

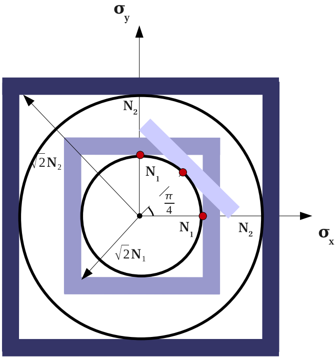
To optimize the performance of a collimaton system it should be considered from the **early design stages** (e.g. avoid space contrains).

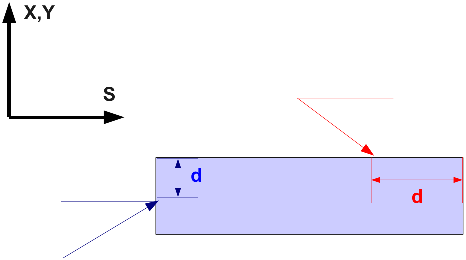
First beam halo estimation based in **CERN PS operation** (ongoing studies, see Ji's talk WE02C02).

- For an improved machine like PS2, $I_{halo}$= 3% $I_{total}$ is a conservative assumption.
- Considering CERN Fixed Target beam → $P_{3\%} \approx$10 kW.

# Collimation Concept and Parametrization

- Slow diffusion process drives particles to impact tangentally to the jaw. The collimators remove these particles at a defined amplitudes. The diffusion velocity ($v_{\mathrm{diff}}$) and and local optics determine the impact parameter ($d$).



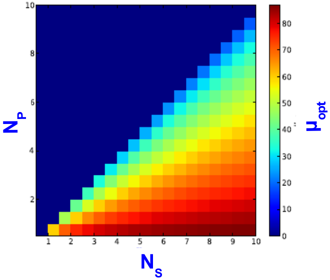


# Collimation Concept and Parametrization

- **Relative phase advance** between the primaries and secondaries defines the maximum seconday halo escaping. For the case of 1-dimesional scattering, the geometrical secondary halo is minimized for $\mu$,

$$\mu_{\mathrm{opt},1} = \cos^{-1}\left(\frac{\mathrm{N_P}}{\mathrm{N_S}}\right), \ \mu_{\mathrm{opt},2} = \pi - \mu_{\mathrm{opt},1}$$

  Existing theoretical studies and dedicated codes (e.g. DJ) consider scattering in all azimuthal directions (no applicability in PS2 case, see later).



- **Orthogonal scattering** to the collimation planes depends on the ratio between $\beta$-functions in the location of the scatterers. PS2 **superelliptical vacuum chamber** (n=3) increase acceptance in diagonals.

$$\epsilon_{\mathrm{x,y}} = \epsilon_{0,\mathrm{x,y}} + \beta_{\mathrm{prim,x,y}}\theta^2_{\mathrm{x,y}}$$

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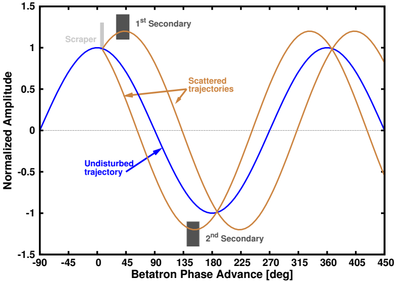

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# Setting Up the Simulations: Codes

State-of-art of collimation tools used in LHC and RHIC beam loss pattern studies (see Ralph's talk MOIB03).
PS2 case: new lattice and aperture model + K2 energy upgrade.

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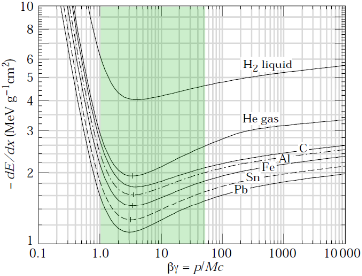

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  3. Point like interactions (Rutherford scattering, coherent and incoherent scattering)

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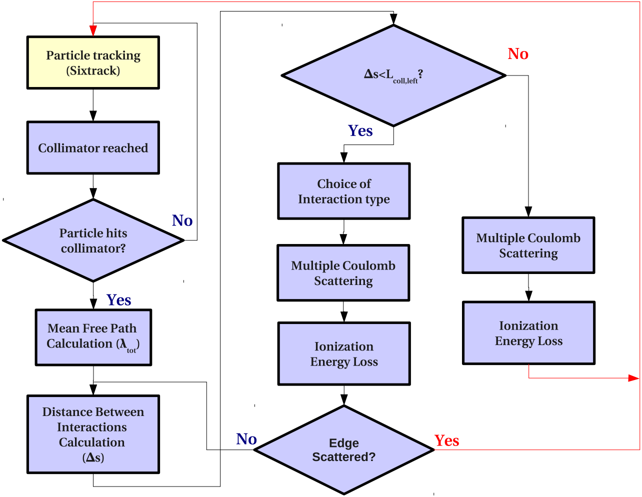
- Loss location determination, trajectories comparison with machine aperture model.

# Setting Up the Simulations: Codes[1]



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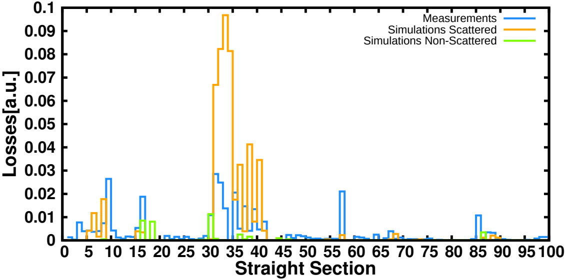
[1] N. Catalan-Lasheras, PhD 1998 and G. Robert-Demolaize, PhD 2006.

# Setting Up the Simulations: Codes Benchmarking

Code benchmarking in range $E_{kinet}$ ~1-50 GeV with BLMs measurements during the Continuous Transfer Extraction at the CERN PS[2]
The aim of this process is to extract the beam in five equal intensity slices by of an electrostatic septum. Particles scattered by the blade caused radiation concerns.



Benchmark parameters:

1. beam loss location
2. equal intensity extraction
3. overall global extraction efficiency

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[2] Results in press, PRSTAB J. Barranco and S. Gilardoni, *"Studies of Losses During Continuous Transfer Extraction at the CERN Proton Synchrotron"*.

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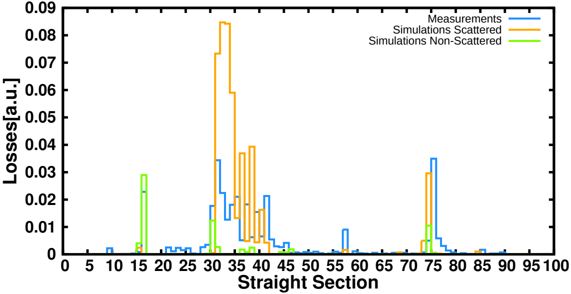

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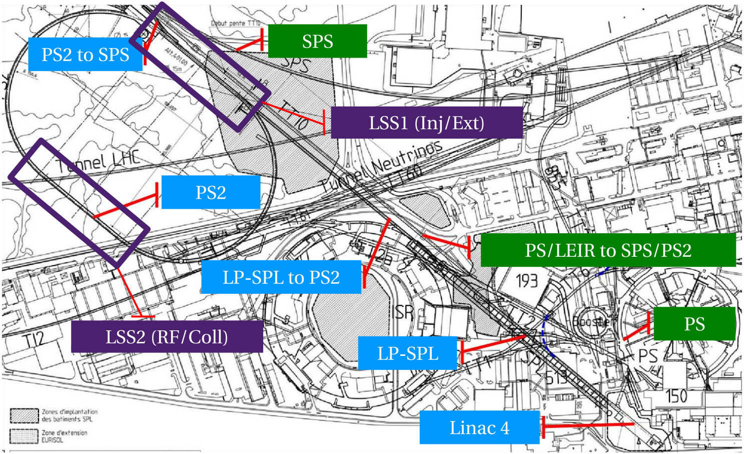


PS2 to SPS

SPS

LSS1 (Inj/Ext)

PS2

PS/LEIR to SPS/PS2

LP-SPL to PS2

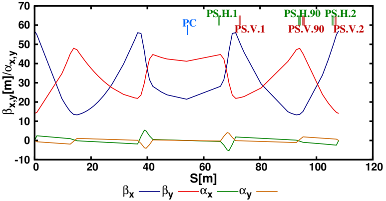
LSS2 (RF/Coll)

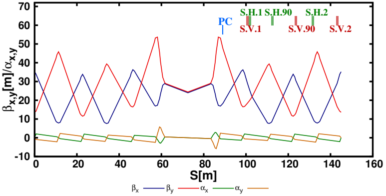
PS

LP-SPL

Linac 4

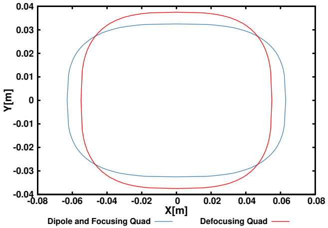
# Setting Up the Simulations: PS2 Model





Courtesy W. Bartmann

| Parameter | Doublet | Triplet |
|---|---|---|
| Length [m] | 107.9 | 145.0 |
| $\beta_{x,y,prim}$ [m] | (21.4,41.2) | (18.1,48.4) |
| $\alpha_{x,y,prim}$ [-] | (0,0) | (-0.6,2.3) |
| $\Delta\mu_{coll,x,y}$ [deg] | (124,100) | (198,144) |
| $N_P$ [$\sigma$] | 2.5 | 3.5 |
| $N_S$ [$\sigma$] | 3.0 | 4.0 |
| $\mu_{opt,x,y}$ [deg] | (29,151) | (31,149) |



Momentum collimation **only possible in dispersion suppressor** (not shown here).

# Setting Up the Simulations: Length of the Scatterer

In the case of thin scatterers ($l_{\mathrm{scatt}} \ll \lambda_I$) at first approximation the scatterer length consideres only Multiple Coulomb Scattering. A Gaussian approximation for the central 98% of the projected angular distribution, with a width given by

$$\theta(x) = \frac{13.6\ \mathrm{MeV}}{\beta_{\mathrm{rel}} c p} \sqrt{\frac{x}{\chi_0}} \left(1 + 0.038 \ln \frac{x}{\chi_0}\right)$$

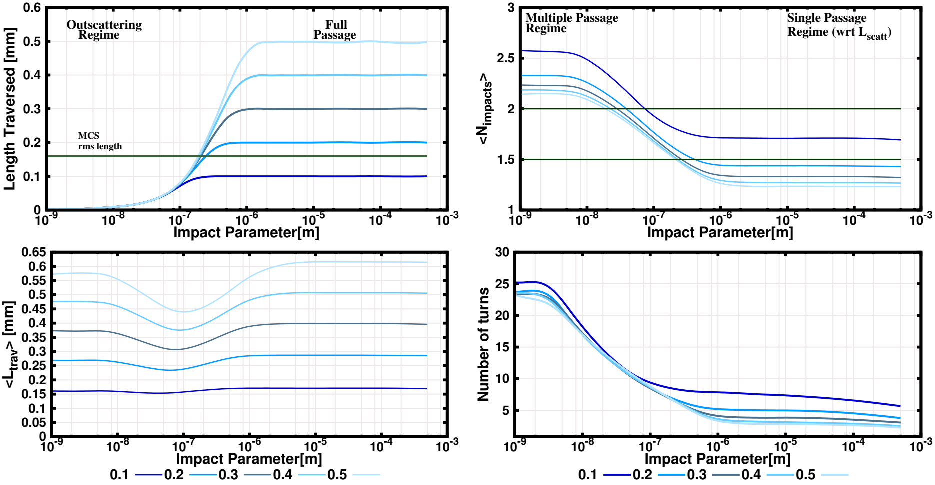
Considering the optics and apertures for the two long straight section considered we obtained the following values,

| **Material** | $\chi_0$ **[cm]** | $L_{\mathbf{Doublet,x,S}}$ **[m]** | $L_{\mathbf{Triplet,x,S}}$ **[m]** | $L_{\mathbf{Doublet,y,S}}$ **[m]** | $L_{\mathbf{Triplet,y,S}}$ **[m]** |
|---|---|---|---|---|---|
| **C** | 19.32 | 0.006 | 0.01 | 0.0008 | 0.003 |
| **W** | 0.3504 | 0.0001 | 0.00016 | 0.00004 | 0.00005 |

First iteration with heavy Z materials (**Tungsten**) for scatterers and secondaries (1 m long) secondaries maximize absorption probability. FLUKA simulations already confirmed that **energy deposition and temperature rise are not an issue for the secondaries**.

# Cleaning Efficiency Optimization

Particle iteration with the scraper will define the efficiency regime.

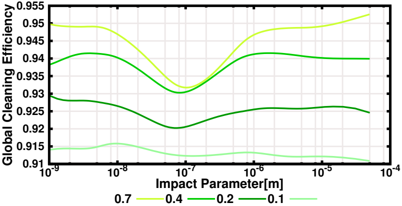


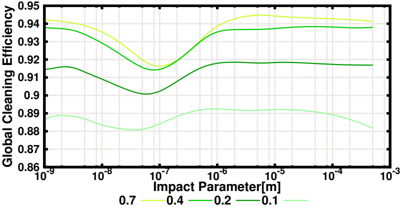
# Cleaning Efficiency Optimization

We define the cleaning efficiency of a collimation system as,

$$\eta_{\text{eff}} = 1 - \eta_{\text{ineff}} = 1 - \frac{\dot{N}_{\text{p,lost}}}{\dot{N}_{\text{p,total}}},$$

Results for an horizontal halo (right) and vertical (left).

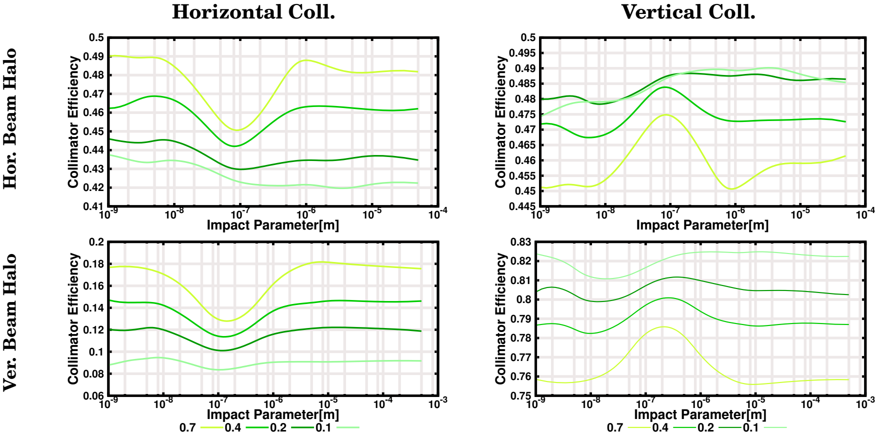




Results of doublet version LSS are not discussed in detail here. Similar patterns are found, the lack of optimal phase advances lower efficiency to an average of **93% for an horizontal halo** and **90% for a vertical**.

# Cleaning Efficiency Optimization

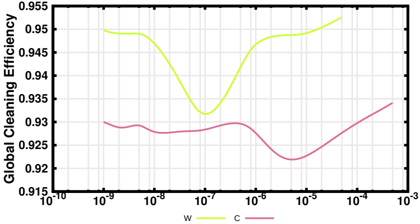
The orthogonal scattering makes the vertical collimators absorb almost 50% of an horizontal halo.

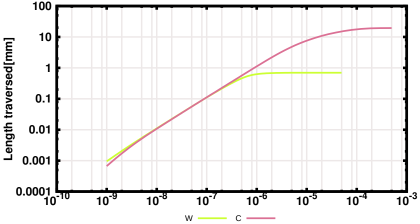


| Halo | SC.1.H eff[%] | SC.1.V eff[%] | SC.90.H eff[%] | SC.90.V eff[%] | SC.2.H eff[%] | SC.2.V eff[%] |
|---|---|---|---|---|---|---|
| Horizontal | 34 (34) | 30 (33) | 10 (-) | 15 (-) | 10 (16) | 1 (6) |
| Vertical | 1 (2) | 42 (48) | 16 (-) | 30 (-) | 1 (3) | 10 (47) |

# Cleaning Efficiency Optimization

The comparison of efficiency profile for different materials for an adjusted the scatterer length (here $L_W$= 0.0007 m and $L_C$=0.02 m) reveals a **displacement in the cleaning efficiency minimum towards larger impact parameters.**

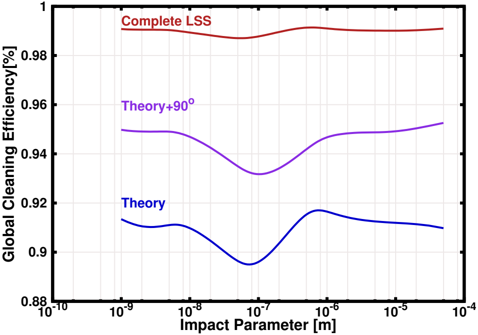


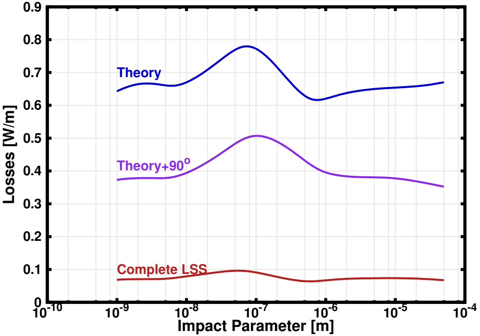


More uniform behaviour for Copper in case of slow diffusion processes. However as larger scatterer lengths needed for lighter materials more nuclear scattering is expected.

# Cleaning Efficiency Optimization

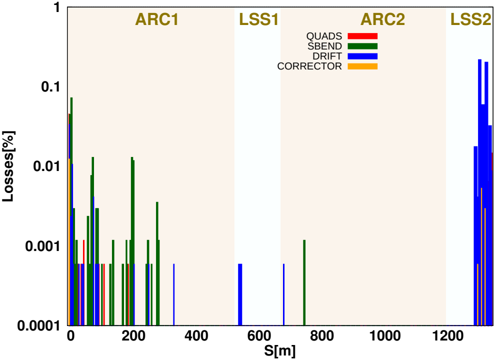
The validation of the system is done against 1 W/m threshold for $P_{halo}$= 10 kW. All different configurations fullfilled the requirements in terms of average losses with improvement margin adding additional collimators.





# Cleaning Efficiency Optimization

Peak losses occur in the collimation region[3] and beginning of ARC1. On the other hand, sensitive areas as injection and extraction (LSS1) and



Ongoing FLUKA simulations with complete magnets geometry and radio protection experts shielding evaluation will give ”green light“.

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[3] Losses in the collimators not depicted

# Conclusions & Outlooks

- Sixtrack+K2 package validated and used in the 1-50 GeV range (collimation and extraction studies).
- A theoretical two stage betatron collimation system with fullfills the PS2 requirements for average uncontrolled losses (1 W/m). Additional collimators in the collimation region could improve efficiency if needed.
- Initial beam halo distribution will define a minimum in the cleaning efficiency (up to 2 units less), related to the number of impacts in the scraper. Lighter materials displaced the minimum towards faster diffusions.
- The **orthogonal scattering** contribution has been demonstrated and raise beam loading concerns in the vertical collimators.
- Energy deposition studies have to certify the **survival of the scatterers**. Secondaries not an issue.

Thanks for your attention!